Title:
An Energy Saving Approach for Rough Milling Tool Path Planning

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Introduction:
A huge amount of energy is required when machining complicated parts with large size such as turbine blades and vehicle molds. Especially in roughing stage, energy consumption is extremely large and strongly affected by three parameters: axial depth of cut a_p , radial depth of cut a_e and feed rate f . On the other hand, these cutting parameters are also physically constrained by a critical cutting force. Previous study concerning energy consumption such as [1] presented a rough trend that an increasing material removal rate would lower the specific energy, thus improve the energy efficiency. However, a more quantitative study is still needed to answer a perceptive question: how each cutting parameter affects the energy efficiency individually, and how to obtain an optimal set that consumes the least energy in terms of rough milling?

To answer this question, we plan to derive an energy consumption formula specifically in terms of these three cutting parameters, with which an optimal set of parameters is determined for a particular machine tool. A tool path strategy based on these parameters should be developed exclusively for a three axis machine tool that not only improves energy efficiency but also remains under a safety level of cutting force at all the time.

The main Idea:
A well-known criterion to assess energy efficiency in CNC machining is the specific energy, which essentially represents the amount of energy per unit volume of removed material. In general, the power demand for CNC machine is comprised of idle power and cutting power, with the first one being simplified as a constant, the cutting power demand is the product of cutting torque and spindle speed. Therefore, the specific energy E_s can be formulated as a function of cutting parameters, i.e. $E_s\ a_p, a_e, f$. However, these parameters should also be physically constrained under a critical cutting force F_0 value to avoid tool damage, formulated as: $F\ a_p, a_e, f\ < F_0$. Thus, the whole issue can be converted into an optimization problem: find an optimal set of parameters so as to minimize $E_s\ a_p, a_e, f$ while $F\ a_p, a_e, f\ < F_0$.

After that, with regard to the design surface, a tool path is generated based on the previously obtained parameters. To really make the machining process energy-efficient, the parameters along the tool path should be largely close to the optimal ones. Two different strategies for tool path planning are developed and explored, known as the constant z-level strategy and the optimized morphing strategy, as shown in Fig. 1.

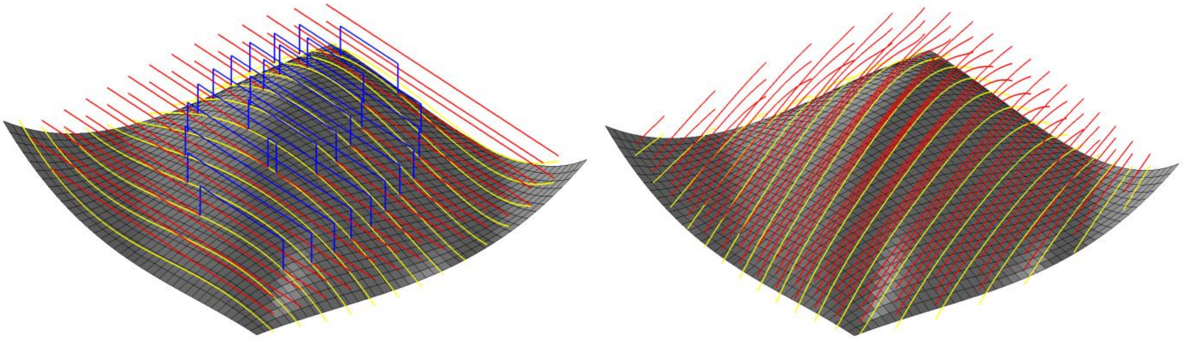

Fig. 1: Two different tool path strategies for surface roughing: (a) constant z-level strategy; and (b) optimized morphing strategy.

Compared with traditional roughing process, both strategies show noticeable reduction in energy consumption when adopted with the optimal cutting parameters. With a shorter length, the constant z-level strategy requires even lower energy consumption but a worse surface quality. While the morphing strategy gives a smoother tool motion, better surface quality, but a slightly larger energy usage. To our expectation, as the idle power usually takes a large percentage of the total power demand, the tool path with optimized cutting parameters also tends to decrease the total machining time under the same level of surface quality in terms of cusp height.

Conclusions:

Even though an increased productivity (large material removal rate) is the key factor to enhancing the energy efficiency, as the idle power in most machine tools takes over a large percentage of total power demand, there are still multiple ways to reach the largest allowable machining productivity (under given physical constraints), which exhibit different effectiveness towards energy efficiency. Therefore, a new energy saving tool path planning in three axis machining is proposed and experimented by us. The optimal cutting parameters, including the axial and radial depth of cut, and the feed rate, are determined towards the goal of minimum specific energy. In our preliminary tests, by utilizing the proposed tool path strategy with the optimal cutting parameters, up to 30 percent of energy can be saved, as compared to some leading commercial solutions.

References:

[1] Diaz, N.; Redelsheimer; N.; Dornfeld, D.: Energy consumption characterization and reduction strategies for milling machine tool use, Glocalized Solutions for Sustainability in Manufacturing, 2011, 263-267. http://dx.doi.org/10.1007/978-3-642-19692-8_46

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